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Nail and screw withdrawal resistance of Scots pine and poplar wood

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ABSTRACT

In this study, the nail and screw withdrawal resistance of Scots pine (*Pinus sylvestris*) and hybrid poplar (*Populus* spp.) species was tested according to the requirements of the relevant standard. The variation in the results of tangential and radial direction of nail and screw withdrawal resistance was negligible. In all cases, the withdrawal resistance was higher in the lateral direction than in the fibre direction, in agreement with literature findings. At the same time, the results of poplar were always lower than the results of Scots pine, in many cases only half of it. Comparing the two species and their anatomical directions, there are no significant differences in the deviances of the sample groups. The differences between the two species can be explained mainly by the density and the anatomical structure. The results suggest that poplar can be used for structural purposes in the same way as Scots pine, but a higher amount of fasteners is required to ensure the strength of the joints.

INTRODUCTION

Studying the nail and screw withdrawal resistance of wood is a very important research area, as nails and screws are used to make many joints, which are even used in structural systems. The knowledge on this topic can be used mainly at the production of furniture elements, crates, interior design objects, pallets and wood structures. The resistance is influenced by many factors, including wood species, moisture content, fastener design, anatomical direction, density, etc. (Molnár 1999). When a nail penetrates the wood, resistance occurs, causing the fibres in its path to split, bend or break. At this moment, compressive force is created, which the fibres exert on the surface of the nail, resulting in an adhesion friction force, which ensures that the nail is held firmly in the material. The screw also functions on a similar principle, with the addition that its thread creates axial forces in addition to the friction, resulting in a significantly higher joint strength. Standards have been developed for testing the nail and screw withdrawal resistance to standardise the measurement results and make it easier to design joints with nails and screws. For our study, the Hungarian standard MSZ 12849 (1980) was used. The aim of the study was to ascertain whether hybrid poplar is suitable for safe structural use in terms of withdrawal resistance of the fasteners. We compared its withdrawal resistances to the long-established and widely used pine by anatomical direction, and also quantified the difference in withdrawal resistance between nails and screws. The standard deviation of the results provided an indication of the reliability of the fastener type.

EXPERIMENTAL METHODS

The nail and screw withdrawal resistance was tested on 31 Scots pine specimens (*Pinus sylvestris*) and 32 hybrid poplar specimens (*Populus* spp). Following the requirements of the standard MSZ 12849 (1980), the first step was to design suitable specimens with dimensions 50×50×150 mm (tangential direction × radial direction × grain direction). The tangential and radial directions of the conditioned samples (20 °C and 65% RH) followed the sides of the samples with few exceptions. A total of three nails and three screws were placed on each sample, 1 on the tangential side, 1 on the radial side and 1 in the end-grain, respectively. A standard, commercially available, 50 mm long wire nail and 4x50 mm wood screws were used (Fig. 1).

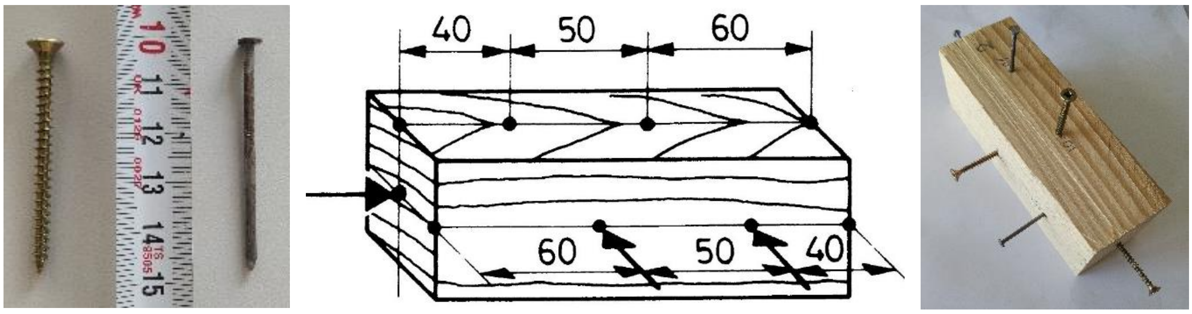

Figure 1: Typical wood screw and wire nail used for the tests (a), the placement of fasteners according to the standard MSZ 12849 (1980) and the placement of fasteners in a specimen (c)

According to the standard, the penetration depth of the nails is 30 mm and the screw drive-in depth is 20 mm, the latter with a pre-drilling depth of 15 mm, using a hole diameter of 2 mm due to the relatively low wood densities, as specified in the standard. For the nails, a slight deviation from the standard was made and they were placed at a depth of 20 mm, thus ensuring better comparability of the two fasteners. The specimens were inserted into a specimen holder designed for a Tinius H10KT universal material testing machine (Tinius Olsen Ltd, Redhill, England) and the settings were adjusted so that failure occurs between 1 and 2 minutes. Accordingly, the loading rates shown in Tables 1 and 2 were used. Different settings had to be used for the nail and the screw, since the withdrawal resistance of a smooth-surfaced nail is significantly lower and therefore faster than that of a screw.

Table 1: Loading rates of the material testing machine during the nail withdrawal resistance tests

	Lateral direction [mm/min]	**Fibre direction [mm/min]**
Scots pine	0.19 mm/min	0.17 mm/min
Hybrid poplar	0.15 mm/min	0.13 mm/min

Table 2: Loading rates of the material testing machine during the screw withdrawal resistance tests

	Lateral direction [mm/min]	**Fibre direction [mm/min]**
Scots pine	0.60 mm/min	0.60 mm/min
Hybrid poplar	0.50 mm/min	0.50 mm/min

Using the tensile forces obtained, the resistance of the wood to pulling out nails and screws ($P_{specific}$) was determined for each specimen and anatomical direction as the ratio of the maximum applied force (F_{max}) and the penetration depth of the fastener (l): $P_{specific}=F_{max}/l$.

RESULTS AND DISCUSSION

Evaluating the test results, it was clear that the withdrawal behaviour of the screws was much more uniform compared to the nails. When testing screw withdrawal resistance, the failures could be grouped into roughly the same time and force intervals, so there was not much variation in this respect. For both wood species, there were measurements exceeding the two minutes standard time for both tangential and radial direction. These tests took on average 30-40 seconds longer. The extra time was presumably caused by the fact that these screws were not perfectly perpendicular to the wood surface due to preparation failures. Thus, the withdrawal force was applied differently, and extra time was required to bend the screws because the tension was in the vertical direction. When the screw position was correct in terms of wood surface and tension force, the process could continue with full force application until failure occurred. These test results were omitted from further analysis. For screws placed in the end-grain of the specimens, no such problem was observed. The settings were found to be adequate, as the process was completed without exceeding the time limit indicated in the standard in all cases.

For nails, there was a very large deviation in test time, so it was not possible to predict at what force, i.e. when the failure would occur. Despite the large deviation, the tests were successful as not only the test duration averages but also their deviations were well between 1 and 2 minutes. For both species, the nails in the tangential and radial directions required precise machine adjustment, because, unlike the screws, failure occurred at very low forces. There were three cases when the machine could not even apply a measurable force to the specimens, because the adhesion friction was eliminated by the weight of the specimens (pine approx. 220 g; poplar approx. 140 g). The moisture content of the wood may explain this problem. For a screw, the joint is assured regardless of the moisture content, but this is not necessarily the case for a nail. According to Kovács (1979), the joint between the nail and the wood is much stronger when the wood is wet. Presumably, in the 3 cases mentioned, sudden loss of moisture could have occurred in the wet pockets, formed in the wood during drying, where the nails were placed. Thus there was the potential for rapid moisture loss, resulting in a significant decrease in joint strength. As unsuccessful measurements, these were not included in further analyses.

The results for the tangential and radial directions, as well as for the transition directions between tangential and radial, showed negligible differences. Accordingly, they will be treated together as lateral resistance in the following. The screw withdrawal resistance in the fibre direction were found to be higher for pine than for poplar (76.0 N/mm and 41.0 N/mm, respectively). The same was found for the lateral direction (95.0 N/mm and 71.6 N/mm, respectively), as shown in Fig. 2. For nails, the same values were 6.6 N/mm and 3.9 N/mm in the fibre direction and 8.3 N/mm and 4.5 N/mm in the lateral direction, respectively. The withdrawal resistance of the fasteners in the fibre direction was therefore 57.4-84.9% of the lateral direction, which is in agreement with the literature (Kovács 1979, Molnár 1999). Presumably, the lateral resistances are higher for both species because less splitting occur in the lateral direction than in the end-grain when the fasteners are inserted, so that a more durable joint between the fastener and the wood can be formed. It can also be concluded that the screw joint is least an order of magnitude stronger than the nail joint, regardless of the wood species and the anatomical direction. The diagram in Fig. 2 illustrates the average and the standard deviation of the calculated results by species and anatomical direction.

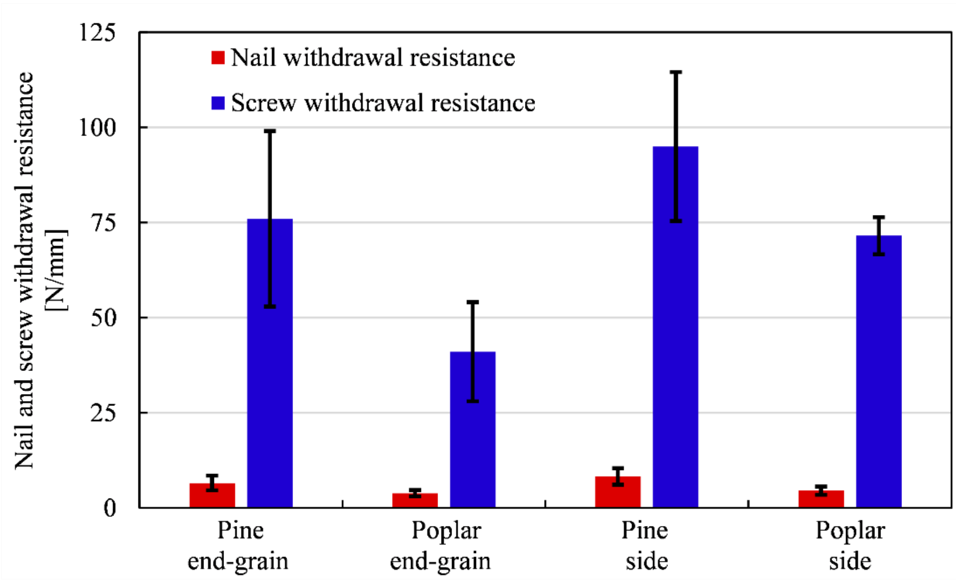

Figure 2: Diagram of the specific nail and screw withdrawal resistance of Scots pine and hybrid poplar categorised by the anatomical directions

Analysing the results, there were some data that significantly increased the coefficient of variation. The increase in standard deviation may be due to measurement errors. There were a small number of specimens with larger slivers protruding from the plane of the wood. When the test started, the protruding slivers were the first to take up the forces and the energy was used to bend them. In these cases, the measured resistance increased significantly, resulting in disproportionately high specific nail and screw withdrawal resistance. The coefficient of variations ranged between 20.6% and 31.8%, still within an acceptable range, with one exception. For the lateral screw withdrawal resistance of poplar, a coefficient of variation of 6.8% was obtained, while the number of measurements was similar to the other sample sets. The screw withdrawal resistance of the hybrid poplar was only 54.0% of the screw withdrawal resistance of the Scots pine in the fibre direction, while it was 75.4% in the lateral direction. The same for the nail withdrawal resistance were 58.8% and 54.6%, respectively. Taking into account the measurement methods and the structural properties of the wood specimens, it can be concluded that pine is much better than poplar wood in terms of nail and screw withdrawal resistance. This finding does not, of course, mean that poplar is not suitable for structural purposes using nails or screws. In terms of withdrawal resistance, the higher density of pine wood ensures better results, and consequently more/stronger joints are required when using poplar wood. From an industrial point of view, this may be somewhat disadvantageous due to a slight increase in both material and tooling costs and a higher increase in labour time. On the other hand, if local poplar timber can be used instead of pine derived from far away, as in the case of Hungary, the lower transport and handling costs are likely to compensate for the loss of more fasteners.

CONCLUSIONS

The nail and screw withdrawal resistance of Scots pine (*Pinus sylvestris*) and hybrid poplar (*Populus* spp.) wood species was investigated. In all cases, the differences in the results of the tangential and radial directions were insignificant and were treated together for the analysis. The withdrawal resistances in the fibre direction were between 57.4% and 84.9% of the lateral ones. At the same time, the nail and screw resistance of poplar was lower than that of Scots pine in all cases. The screw withdrawal resistance of the hybrid poplar was 54% compared to the withdrawal resistance of Scots pine in the fibre direction and 75% in the lateral direction. The nail withdrawal resistance of the hybrid poplar was 59% in the fibre direction and 55% in the lateral direction compared to that of the Scots pine. In other words, the quantity/size of the fasteners should be increased significantly when using poplar for structural purposes. This is especially true for nails, as the strength of this type of joint is much less reliable. It is also useful to know that a screw joint provides at least an order of magnitude stronger withdrawal resistance than a nail joint.

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